TABLE 3.—*Correlation periodogram of English rainfall*—Continued

Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram		Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram	
	r_l	$r_l/\sigma r_l$	Part A	Part B		r_l	$r_l/\sigma r_l$	Part A	Part B
303	−0.066	−1.48	+0.39	−2.18	316	−0.080	−1.78	−1.58	−0.98
304	+.004	+.08	+.77	−.56	317	+.069	+1.53	+.46	+1.58
305	−.002	−.03	−.28	+.18	318	+.022	+.50	+.42	+.30
306	+.014	+.31	+.67	−.14	319	+.009	+.19	−1.26	+1.26
307	−.009	−.20	−.69	+.29	320	−.045	−1.00	−.23	−1.11
308	−.001	−.03	−.19	+.12	321	−.036	−.80	−.63	−.50
309	−.027	−.60	+.66	−1.28	322	−.013	−.30	+.80	−1.02
310	+.028	+.63	−.95	+1.56	323	−.051	−1.12	−1.82	+.04
311	−.020	−.45	+.28	−.80	324	−.049	−1.08	−.92	−.63
312	−.008	−.17	−.81	+.43	325	−.059	−1.31	−1.31	−.60
313	−.007	−.15	+.34	−.47	326	+.061	+1.34	+.51	+1.30
314	−.090	−2.01	−1.72	−1.18	327	−.025	−.55	−1.54	+.55
315	+.035	+.78	+1.21	+.02	328	−.001	−.15	−.70	+.55

TABLE 3.—*Correlation periodogram of English rainfall*—Continued

Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram		Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram	
	r_l	$r_l/\sigma r_l$	Part A	Part B		r_l	$r_l/\sigma r_l$	Part A	Part A
329	−0.014	−0.30	+0.36	−0.67	341	+0.086	+1.86	+0.98	+1.52
330	+.071	+1.55	+1.38	+.87	342	+.042	+.91	+.60	+.68
331	−.035	−.76	+.07	−1.03	343	−.022	−.47	−.60	−.12
332	−.057	−1.25	−.90	−.88	344	−.016	−.34	−1.21	+.58
333	+.054	+1.19	+.73	+.93	345	+.016	+.34	−.21	+.62
334	+.007	+.15	−1.24	+1.21	346	+.012	+.26	−1.23	+1.38
335	−.023	−.50	+.32	−.91	347	+.045	+.98	+.77	+.74
336	+.025	+.55	+1.29	−.37	348	−.063	−1.36	−2.07	−.02
337	−.022	−.48	−1.05	+.25	349	+.011	+.23	+.20	+.13
338	+.109	+2.37	+1.41	+1.90	350	+.018	+.39	+.31	+.24
339	+.080	+1.74	+.48	+1.88	351	+.061	+1.30	+.39	+1.37
340	−.002	−.04	−.98	+.77	352	−.032	−.69	−1.86	+.70

SIGNIFICANT CHANGES IN THE RAINFALL AT SOME LOCALITIES

By DEAN A. PACK

INTRODUCTION

These data are presented to support the generally prevalent, though many times questioned, belief in weather recurrences and weather cycles. No attempt has been made to establish any direct or indirect relation between precipitation and sun-spot cycles or any other kind of periodic variation. However, an effort has been made to show that precipitation cycles do exist, and that the precipitation for many different localities show significant changes from period to period.

SUMMARY

These points have been supported by the calculation of cycles for several precipitation records, and by showing that the differences in the amount of rainfall during the maximum and during the minimum periods for these records could not be due to chance alone.

A cycle or trend for each precipitation record was calculated and the curve plotted, so that the periods of high or low average rainfall could be located. This was done for the annual precipitation records of 41 stations in the United States and 12 stations in other parts of the world. The crests and troughs of these curves indicated periods of maximum or high average and periods of minimum or low average rainfall for each station, respectively. The annual precipitation during the periods of maximum rain fall were compared statistically with the annual precipitation during the periods of minimum rainfall for each station. The results show that the precipitation for each station passes through a particular cycle during which time it varies by significant amounts. As a result there are significant maximum and minimum periods.

The annual precipitation during successive maxima periods and minima periods were also statistically compared. No significant difference of average annual precipitation was found between successive maxima periods or between successive minima periods for any particular station. While this indicates that successive cycles may have about the same amplitude, no definite conclusion is possible because our weather records are too short.

HISTORICAL

Sir Richard Gregory's (**6**) address before the Royal Meteorological Society will be found of interest as a review of the present opinion on weather cycles and of the more recent literature. In 1915 Goodnough (**3**) pointed out that the rainfall for various localities in New England changed from time to time. In 1930 he (**4**) presented the following table 1 which is self-explanatory and which is reprinted here by permission of the New England Water Works Association.

TABLE 1.—*Average annual rainfall by periods* (*inches*)

Period	New Bedford, Mass.	Boston, Mass.	Waltham, Mass.	Lowell, Mass.
1826–49, 24 years	47.21	42.00	41.13	39.45
1850–76, 27 years	46.73	53.18	43.00	45.73
1877–1903, 27 years	47.79	45.52	44.40	45.95
1904–29, 26 years	44.23	40.32	40.24	41.43
1826–1929, 104 years	46.49	45.40	42.24	43.26

Marvin (**7**) in an article entitled "Concerning Normals, Secular Trends and Climatic Changes" discussed the precipitation changes for Boston vicinity from 1758 on. Powell (**8**) presented a method for finding long period cycles and showed that a cosine curve fits the Boston precipitation data much closer than straight line trends.

SOURCES OF MATERIAL

The data used for these calculations were taken from the records of the United States Weather Bureau, the New England Water Works Association, the Smithsonian Institution (1), and the Meteorological Service of Canada.

INVESTIGATION

The Goutereau (**5**) Ratio was applied to several annual precipitation records, with a result that the data indicated the presence of a cycle.

In order to select periods from the annual precipitation records that had a high or low average annual precipitation, cycles were calculated and curves drawn for the precipitation record of each station. These cycles were calculated by the least squares method or by moving averages. The least square method was used only on parts of long records that could be represented by more simple curves. From these curves, it was an easy matter to select from the records periods having either a high or a low average annual precipitation.

An idea of the fit of the curves used in this work may be had by comparing the curve for the annual precipitation of Boston with Powell's (**8**) long period cycle for Boston calculated by a method of successive integration.

Boston precipitation

	Powell	Author
Period for data used	1818–1928	1818–1931
Normal	44.34	44.30
Date of recent minimum	1911	1910½
Date of earlier minimum	1815	----------
Date of recent maximum	1865	1865
Average deviation from cycle	4.28	4.23

While some of the curves may not be exact and represent the best fit, it is believed that any one of them fits the data more accurately than would a straight line.

After the curves were drawn samples were taken from the annual precipitation records of each locality and compared statistically to determine whether or not the amount of rainfall had changed from time to time. One sample representing maximum rainfall and one sample representing minimum rainfall were taken from each annual precipitation record at the points indicated by the crest and the trough of the curve, respectively. Each sample consisted of the recorded annual precipitation for the particular locality during a period of 10 or 30 consecutive years. In order to avoid any effect that might be due to the natural *order of succession* (**10**), the order of the annual precipitation values for each one of all samples was determined by chance and so arranged before the statistical analysis was commenced. After the annual precipitation values or raw data in both maximum and minimum samples for any locality were arranged by chance, the samples were analyzed to determine if they were significantly different or not. The method used for calculating these results which are given in table 2 was that given by Fisher (**2**) under section 24, pages 104–107. If there was any question as to the value of P obtained by this method it was checked by the method he gives in section 24.1, pages 107–111.

Table 2.—*Probability that the difference found between the maximum and minimum rainfall for 10- and 30-year periods might be due to chance only*

No.	Locality	Part of record from which samples were selected		Mean annual precipitation during the periods of—		Probability, *P*
		Maximum	Minimum	Maximum	Minimum	
				Inches	*Inches*	
1	Albany, N.Y	1867–76	1905–14	42.96	29.84	0.01
2	Amherst, Mass	1895–1904	1905–14	47.60	39.68	.01
3	Austin, Tex	1873–82	1889–98	53.43	36.15	.01
4	Boise, Idaho	1869–78	1920–29	15.53	11.80	.06
5	Boston, Mass	1861–70	1905–14	57.25	35.22	.01
5a	do	1851–80	1896–25	51.95	38.55	.01
6	Burlington, Vt	1860–69	1907–16	36.48	28.35	.01
7	Cambridge, Mass	1854–63	1909–18	51.98	37.61	.01
8	Charleston, S.C	1864–93	1896–1925	55.68	41.05	.01
9	Chicago, Ill	1876–85	1910–19	39.78	30.49	.01
10	Cincinnati, Ohio	1875–84	1894–1903	46.87	32.57	.01
11	Concord, N.H	1884–93	1908–17	40.04	32.98	.01
12	Cornish, Maine	1893–1902	1874–83	52.50	42.06	.01

Table 2.—*Probability that the difference found between the maximum and minimum rainfall for 10- and 30-year periods might be due to chance only*—Continued

No.	Locality	Part of record from which samples were selected		Mean annual precipitation during the periods of—		Probability, *P*
		Maximum	Minimum	Maximum	Minimum	
				Inches	*Inches*	
13	Denver, Colo	1906–15	1893–1902	16.29	12.70	0.04
14	Gardner, Maine	1850–59	1905–14	48.28	38.62	.01
15	Hartford, Conn	1888–97	1909–18	49.76	39.27	.01
16	Lakeport, N.H	1884–93	1905–14	45.64	37.12	.01
17	Key West, Fla	1878–97	1890–99	42.50	34.62	.21
18	Lowell, Mass	1881–90	1837–46	42.76	36.65	.01
19	Marietta, Ohio	1859–68	1836–45	44.75	38.57	.20
20	Middletown, Conn	1894–1903	1910–19	51.91	41.26	.01
21	New Bedford, Mass	1868–77	1909–18	48.93	41.45	.02
22	New Haven, Conn	1873–82	1891–1900	52.14	42.30	.01
23	New Orleans, La	1871–80	1890–99	65.47	46.99	.01
24	New York, N.Y	1884–93	1834–43	48.81	35.56	.01
24	Omaha, Nebr	1875–84	1910–19	39.22	23.75	.01
26	Philadelphia, Pa	1865–74	1877–86	50.44	36.70	.01
27	Portland, Maine	1884–93	1905–14	47.23	37.36	.01
28	Portland, Oreg	1874–83	1916–25	56.70	38.20	.01
29	Providence, R.I	1868–77	1832–41	49.53	37.96	.01
30	Sacramento, Calif	1860–69	1916–25	19.60	13.77	.01
31	St. Paul, Minn	1865–74	1923–32	32.19	24.09	.01
32	Salt Lake City, Utah	1906–15	1887–96	17.45	14.71	.01
33	San Diego, Calif	1877–86	1892–1901	12.24	7.69	.06
34	San Francisco, Calif	1880–89	1897–1906	25.06	18.88	.07
35	Santa Fe, N.Mex	1874–83	1917–26	15.64	13.22	.23
36	Springfield, Mass	1884–93	1909–18	49.00	37.61	.01
37	St. Louis, Mo	1846–55	1894–1903	47.54	34.67	.01
38	Waltham, Mass	1884–93	1837–46	47.53	39.08	.01
39	Washington, D.C	1882–91	1921–30	48.15	38.40	.04
40	Winnemucca, Nev	1878–97	1910–19	10.00	8.02	.11
41	Yuma, Ariz	1905–14	1875–84	4.86	2.66	.12
	FOREIGN STATIONS					
42	Berlin, Germany	1860–69	1911–20	6.22	5.32	.02
43	Calcutta, India	1862–71	1889–98	72.60	55.58	.04
44	Cape Town, South Africa	1883–92	1864–73	30.37	23.33	.01
45	Copenhagen, Denmark	1824–33	1881–90	6.36	5.20	.04
46	Greenwich, England	1872–81	1893–1902	68.18	54.46	.01
47	Honolulu, T.H	1895–1904	1905–14	38.23	22.22	.01
48	Madras, India	1839–48	1828–37	57.58	38.16	.01
49	Rome, Italy	1898–1907	1832–41	1,020.6	641.5	.01
50	Sidney, New South Wales	1870–79	1901–10	55.54	39.10	.01
51	St. Johns, Canada	1890–99	1878–87	59.47	51.40	.03
52	Stykkisholm, Iceland	1896–1905	1877–86	719.7	550.7	.01
53	Toronto, Canada	1861–70	1879–88	35.08	29.97	.01

The limit of the probability *P* for significance in this type of analyses has been placed at 0.05. Therefore, the items with a probability of less than this indicate that the maximum and minimum samples as listed in table 2 and analyzed were found significantly different and that one would not expect to find such differences as due to chance only. The results also show that these stations have maximum periods of 10 years or more in length during which time the rainfall is significantly greater than during the corresponding lengthened minimum period.

The phase of the cycles for some of the stations, as for example Boston, Mass., and Charleston, S.C., were so long that it was possible to select periods of 30 or more years in length having significant maximum and minimum rainfall characteristics.

The probability values for the stations nos. 4, 17, 19, 33, 34, 35, 40, and 41 are large and show that the 10-year maximum periods of rainfall were not significantly different from the minimum periods of rainfall. It was noted that these stations had shorter cycles and the length of the samples were accordingly reduced to 5 years. Table 3 gives the probability values for the significance of the difference between the maximum and minimum 5-year samples taken from these same station records.

TABLE 3.—*The probability that the differences found between the maximum and minimum rainfall for periods of 5 years might be due to chance*

No.	Locality	Part of record from which samples were taken		Mean annual precipitation during periods of—		P
		Maximum	Minimum	Maximum	Minimum	
				Inches	*Inches*	
4	Boise, Idaho	1869–73	1886–70	18.51	11.63	0.02
17	Key West, Fla	1851–55	1859–63	47.03	32.16	.01
19	Marietta, Ohio	1865–69	1891–95	47.15	34.63	.02
33	San Diego, Calif	1886–90	1896–1900	12.28	6.84	.02
34	San Francisco, Calif	1864–68	1897–1901	28.55	20.63	.04
35	Santa Fe, N.Mex	1874–78	1888–92	17.33	12.24	.01
40	Winnemucca, Nev	1883–87	1901–5	9.41	7.22	.04
41	Yuma, Ariz	1905–9	1899–1903	6.80	1.60	.01

While the records for these stations have significant 5-year maximum and minimum rainfall periods, the differences are not so great as found elsewhere.

The differences between the maximum and minimum rainfall for some stations were calculated by Bessel's formula. The mean annual precipitation for Boston from 1851 to 1880 was 51.95 ± 0.91 inches, while that for the minimum period from 1818 to 1847 was 41.07 ± 0.77 inches. The difference between these means is 10.89 ± 1.19 inches or about 25 percent of the recorded mean annual precipitation (41.02 to 1931) for Boston. This mean difference is statistically significant and shows that Boston had significantly more rainfall from 1851 to 1880 than during the earlier period. Another example will also illustrate this point. The mean annual precipitation for Charleston, S.C., from 1864 to 1886 was 56.81 ± 1.68 inches, while that for the period 1841 to 1863 was only 42.70 ± 1.13 inches. The difference between these means is 14.11 ± 1.34 inches and shows a significant difference between the maximum and minimum rainfall periods of Charleston. As significantly different maximum and minimum rainfall periods have occurred in the annual precipitation records of all these stations, it naturally follows that the average annual rainfall (precipitation) at these stations has changed from time to time.

Successive maxima and successive minima periods of rainfall for some of these stations have been compared. The annual precipitation record for Charleston, S.C., extends over two periods of minimum rainfall. The calculated cycle showed these minima to be at 1852½ and 1906. A comparison of the annual precipitation from 1848 to 1857 with that from 1902 to 1911 gave a probability value of 0.70. This indicated that the samples were alike and that one could expect to find similar differences due to chance only. Similar comparisons of the Lowell minima at 1840 and 1913, New Bedford maxima at 1828 and 1893, New Bedford minima at 1841 and 1913, New York City minima at 1838 and 1916, and Waltham minima at 1840 and 1920 gave probability values of 0.22, 0.69, 0.29, 0.25, and 0.81, respectively. All these values are well over 0.05 and indications are that these successive maxima are essentially equal and that these successive minima are also nearly equal.

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A COMPARISON OF DROUGHT CONDITIONS IN GEORGIA AND ARKANSAS

By GEORGE W. MINDLING

[Weather Bureau office, Atlanta, Ga., Jan. 10, 1934]

A study of droughts in Georgia was recently completed following the methods applied by H. S. Cole in his article on Droughts in Arkansas, published in the MONTHLY WEATHER REVIEW for May 1933. It was desired to bring to light what the records show as to frequency of dry spells in Georgia and to compare such frequency with that in Arkansas as well as to examine such other drought conditions as might seem to be of interest.

Mr. Cole used the period of 1898–1930, inclusive, but in Georgia not many original records were found available for years prior to 1900. Therefore, it seemed best to use the period of 1900–1932 partly because the record of a station could be followed more easily in the original records than in the tables of daily precipitation published in monthly reports and partly because by beginning with 1900 it was possible to select 12 well-distributed stations having unbroken records through a 33-year period.

The inherent difficulties in defining drought in terms of rainfall are so generally realized and have been discussed by so many writers that it seems needless now to add to what has already been said on the subject. While no entirely satisfactory definition of drought has been formulated in terms of rainfall, still it is possible to make a valuable comparison of the drought conditions in one State with those of another by applying the same criteria and methods of analysis to the long-period records of a sufficient number of stations in each region.

The tables accompanying this paper present a summary of the results obtained in Arkansas and Georgia. The data for Arkansas have been taken from the published article by Mr. Cole cited above, while those for Georgia were derived by applying the same methods employed by Mr. Cole in his State. It is believed that this comparison may be regarded as a very satisfactory one, since 12 well-distributed stations were used in each State and the period covered by the records was of the same length and nearly identical as to the years included.

Mr. Cole says:

> It was decided to use all 15-day periods without measurable rainfall during the warmer months, May to September, inclusive,